Sugarcane production model and parameters applied to the Brazilian Cerrado

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This document outlines the generalized sugarcane production model and its parameters applied to our study region in southeastern Brazil.

Model summary

We model potential land use decisions of a commercial sugarcane producer with regard to where to plant sugarcane and where to place natural vegetation in compliance with Brazil's Forest Code. The harvested sugarcane is sold to a mill at market prices. Using standard microeconomic theory, the spatial decisions balance the revenue from sugarcane with the costs of production at the pixel level (i.e. 0.81 ha area). The model allows sugarcane to be planted in areas with the highest net revenue and the placement of natural vegetation in areas that incur the smallest foregone profit from sugarcane production. The goal of the sugarcane producer is to maximize net revenue (profit) from sugarcane production while complying with the Forest Code. A generic expression of the profit function is given below:

$$Profit = Price * Yield\ - Production\ costs - Forest\ Code\ compliance\ costs,$$

where the costs and yield pertain to individual pixels. There are currently no monetary benefits to the commercial producer from habitat conservation (such as payments for ecosystem services related to restoring forests or replanting trees).

All of the parameters employ annual average values; we do not model inter-annual variability. We also do not model profit beyond the production of sugarcane (e.g. ethanol production, etc.).

Our model is deterministic and static. We consider period-by-period decisions of where to place sugarcane and natural vegetation. We assume that the storage of sugarcane across periods is not possible and that soil productivity and water availability remain constant through time. We do not attempt to model the sugar content in the harvested sugarcane. It is also important to note we focus on production decisions at the extensive margin (i.e. where to plant sugarcane and natural vegetation) and not on the intensive margin (i.e. how much to produce from a given pixel). We assume that the sugarcane produced is the optimal per pixel given the costs of inputs.

Modeling extent

We assume that land use decisions are bounded by the extent likely to be impacted by sugarcane in the region, which includes the entire Ribeirão São Jerônimo watershed, some small watersheds that flow in to the reservoir, and portions of the Tijuco and Arantes River watersheds (see documentation on TNC website above for further description of the study area). In other words, the commercial agricultural producer considers the pixels outside the watershed as not suitable or unavailable for sugarcane production or for Forest Code compliance. All areas with the exception of the currently developed (urban) areas, roads and water bodies have the potential to become sugarcane fields; this includes natural habitat remnants, pastures, and cropland. The same assumption is made for natural vegetation (only developed areas cannot be converted).

Parameters

This section summarizes the parameters used in the sugarcane model. Even though the sugarcane model is generalized and can be applied to a variety of settings, in this case study we use cost parameters informed by Santa Vitória Açúcar e Álcool (SVAA), which is undertaking large-scale sugarcane production in the study region. For confidentiality reasons we do not present detailed maps and report only summary statistics related to model parameters. All cost data are from 2013.

In cases, where production involves a lump sum cost for the whole sugarcane production cycle (6 years), we convert the costs to annual values, using the formula:

$$annualized\ \ cost = K\frac{\delta(1+\delta)^n}{(1+\delta)^n - 1}$$ (EPA 2007).[1]

The expression gives us the values that, if paid out in equal amounts for *n* years and discounted, would equal the total value of the original cost (K). For the discount rate, δ, we use a weighted average of the five-year interest rates from the Brazilian Central Bank (Source: http://www.bcb.gov.br/Pec/Copom/Ingl/taxaSelic-i.asp#notas).[2]

We do not explicitly model spatial dependence: The yield and costs per pixel do not depend on the values in the adjacent or surrounding pixels. The only exception is for the per-pixel transaction costs associated with leasing a farm (the costs are smaller if a pixel is part of a bigger farm). However, because of spatial correlation in the values from the biophysical model, there is spatial clustering in the values of the output layers.

Sugarcane price (p)

p is the average price per ton of sugarcane in Brazilian Reais ($R) (UDOP – www.udop.com.br). In this model we use a fixed price of 55.35 $R/ton; this is the average over the last three years (2010-2013).

We assume that the commercial producer does not have any price setting power and that the price of sugarcane is determined by a (competitive) market.

Yield

The sugarcane yield per pixel is defined as the amount harvested from a pixel when sugarcane plants are grown in an environment to which they are adapted. Our assumption is that the sugarcane plants are not limited by the availability of nutrients and water and that diseases, pests, weeds, and other biotic stressors are effectively controlled (Evans and Fisher 1999). In our model the yield per pixel i , Q_i, is determined by the soil type and slope:

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[1] EPA Economics & Cost Analysis Support OAQPS Economic Analysis Resource Document. Available at http://www.epa.gov/ttnecas1/econdata/Rmanual2/8.3.html

[2] We used rates for 2008-2013, giving more weight to the values in 2013. The final value used in our models is 10.32%

$$Q_i = (SoilType_i) * Slope_i$$

The values are calculated in metric tons of sugarcane per pixel per year.

The **$SoilType_i$** parameter gives the standard sugarcane yield per pixel for a specific soil type found in our study area (Table 1). We assume yield does not vary *within* the same soil type due to potential edaphic factors (e.g., drainage, texture, or chemical properties such as pH), but varies *between* different soil types.[3] We also assume standard soil preparation and fertilization, which are applied to all sugarcane pixels in our study area in accordance with their soil types.

The yield values are based on empirical estimates of sugarcane yield for the different soil types found in our study area properties (Dias et al. 1999, Maule et al. 2001, Prado 2005). The average productivity per hectare for our study area is 83.36 tons (67.52 tons/pixel), with a range of 68 to 100 tons per hectare (55.1 to 81 tons per pixel). These estimates are consistent with the actual sugarcane production in the 12 municipalities within and surrounding the study area (IBGE 2011) (Table 2).

The **$Slope_i$** parameter is a binary variable, equal to 1 where the slope allows for mechanical harvesting and soil preparation (< 12%) and 0 otherwise. Because mechanized harvesting is not possible on lands with slopes greater than 12%, we assume that there will be no sugarcane production in these areas (Pinto, Bernardes, & Sparovek, 2001; Sparovek, Pereira, Alleoni, & Rosetto, 1997). The slope parameter is based on geospatial elevation data (SRTM).

Note that we assume a static and deterministic model; we do not attempt to incorporate uncertainty in our parameters.

Cost data

We distinguish between sugarcane production costs and Forest Code compliance costs. A detailed list of all cost parameters used in our model is given in Table 3, with their summary statistics for our study area in Table 4.

[3] A large number of factors can affect the productivity of sugarcane--total and seasonal rainfall, temperature, radiation, soil types, slope, irrigation, harvest timing, fertilizer use, crop variety, crop management, and pest control, among others (Dias et al. 1999; Maule et al. 2001; Dantas-Neto et al. 2006; Silva et al. 2009; Batchelor et al., 2002; Monteiro 2012; Prado 2005). We do not aim to develop a comprehensive model that incorporates all possible factors that can affect sugarcane production, but rather focus on the key parameters that influence the spatial variability of the sugarcane yield in the study area. Because of the relatively small size of our study area, we do not observe much spatial variability in precipitation, temperature, or radiation.

Production costs

The production costs include the costs of inputs (e.g., fertilizer, labor, land) needed to produce sugarcane as well as related transaction costs (e.g., obtaining permits). We consider spatially variable and fixed production costs. For confidentiality reasons, we cannot provide values for each type of cost, but instead provide summary statistics of the total production costs per pixel for the whole study area. The definitions and scale of the production costs are summarized in Tables 3 & 4.

Transportation costs (TransCost)

Transportation costs refer to the cost (in $R/pixel) to transport one ton of sugarcane from its place of origin (pixel) to the mill, and is calculated as follows:

$$TransCost_i = Distomill_i * DistanceCost * Q_i + BargeCost_i * Q_i$$

Distomill: Distance in kilometers to the mill from each pixel within a target property. The value is calculated as the sum of the minimum linear distance from each pixel to the farm gate plus the distance from the farm gate to the mill. Here, we assume a linear relationship between travel distance and travel time by road; this assumption seems valid for our study region given that the majority of roads are of one road type (i.e., dirt roads as opposed to paved), which is the main factor influencing travel time.

DistanceCost: Transportation cost per ton per kilometer, assumed to be constant through space.

BargeCost: Cost per ton of sugarcane transported by barge. Barge costs apply to the northeast part of the study area where sugarcane is carried over a channel of the reservoir to avoid the cost of road transportation around the channel. In this case, we calculate the distance by road from the farm to the barge upload site and then from the download site to the mill. The pixels outside this area do not incur any barge costs.

Fertilization cost

This is the cost of fertilizers per pixel per year. This cost depends on the type of fertilizer and the soil type. We assume that the commercial sugarcane producer applies the standard fertilizer amount according to their soil type. In our case study, fertilizer amounts are based on soil productivity which is classified into two groups: high and medium/low fertility.

Leasing cost

Rather than purchasing land, the commercial producer in our models is signing leasing contracts with local farmers to grow sugarcane on their lands. Contracts last for one or two sugarcane producing cycles, corresponding to 6 or 12 years, respectively. For the NPV calculations in our models we assume a standard contract length of 6 years. Because only a small portion of the farms in the region have been leased for sugarcane production, data on actual leasing costs are not available. In the absence of observed leasing costs, we constructed annual cost relationships based on (1) soil type (fertility) and (2) distance to the mill (Kelson Souza, SVAA, *personal communication*). We assume that mill operations will not affect the local land market and that the offered leasing prices are equal to the small holders' reservation prices. The leasing contracts are paid annually based on the value of a ton of sugarcane.

Tree removal

This encompasses the cost of clearing one hectare of remnant paddock trees. It is very common for cattle ranchers to leave isolated, scattered trees (called paddock trees) to provide shade for the cattle. This cost is incurred only with the conversion of pastures to sugarcane fields.

Clearing cost (for natural vegetation outside pastures)

This the cost associated with the mechanical removal of existing natural vegetation remnants outside pastures.

Transaction costs

This category includes costs associated with obtaining permits (Table 3).

Operational costs (OperCost)

- *Harvesting*: This is the cost of operation, maintenance and depreciation of the mechanical harvesters. It is calculated by multiplying the harvesting cost per ton by the potential yield (as described above).
- *Handling*: This represents the cost of loading and unloading the harvested sugarcane. It is calculated by multiplying the handling cost per ton by the potential yield described above.
- *Soil preparation (for expansion areas)*: This cost represents the initial soil preparation in areas which had a different previous use (e.g., cattle ranching). It is incurred only once for the fist-time conversion of land to sugarcane production.

Non-spatial production costs

These include cost of operation support, administration, labor, crop management, soil preparation, planting, and certain transactions costs calculated by pixel (Tables 3 & 4).

These costs do not vary in space and do not depend on yield; thus, they do not affect the ranking of pixels in terms of their profitability, but do affect the estimated profit per farm.

Forest Code compliance costs

The Forest Compliance costs are estimated costs of implementing the legal requirements of Brazil's Forest Code. These include the protection or restoration of habitats as Permanent Protected Areas (PPAs) and Legal Reserves (LR).

Deforestation fines

The Forest Code allows deforestation on farms that exceed the legal requirements. Farmers clearing natural vegetation illegally face fines imposed by the Environmental Agency. These range for R$800.00 to R$2,400.00 for LRs and from R$900.00 to R$2,700.00 for clearing PPAs. The actual values, however, are left at the discretion of the Environmental Agency (Table 4).

Because of the low compliance with the Forest Code among individual landowners (only 15.9% of the properties are potentially in compliance in the study area), we assume that all clearing of natural vegetation within our study area will incur fines.

Restoration costs

The Forest Code stipulates that illegally cleared natural vegetation must be restored to avoid additional fines. Similar to the deforestation costs, we assign the same uniform restoration cost to all pixels currently under natural vegetation. While the costs of conversion and restoration should vary by natural vegetation type, we did not have data on the restoration costs of non-forest areas (e.g. wetlands, cerrado). For this reason we assign the same uniform cost to all pixels that have to be restored to natural vegetation. In our model all restoration costs are incurred only once and do not depend on monitoring or restoration success.

Replanting costs
These costs apply only to areas where the conversion from pastures to sugarcane fields necessitates the removal of paddock trees. Local legislation requires that for each tree removed from a pasture another 10 need to be planted elsewhere. To calculate the replanting cost, within each pasture pixel we counted individual tree canopies using satellite imagery (2.5m resolution). For more details, see the summary on the development of geospatial data for our study area found at: http://www.conservationgateway.org/ConservationPractices/EcosystemServices/tnc_dow_collaboration/brazil/Pages/default.aspx.

Transaction costs
These costs relate to the permits and registration related to environmental licensing.

Comparisons with previous studies
The average production costs per ha for our study area are R$3917.69 /ha (in 2013 terms), with the average Forest Code compliance costs around R$148.52/ha (Table S4). These costs are consistent with the cost estimates from previous studies from the area. For example, Nachilik et al (2013) find production costs vary between R$40.86-61.55/tons of sugarcane (excluding the leasing costs) in a Sao Paulo region. Using the sugarcane yield values for our study area, we convert the costs to R$2778.48-6155.00/ha. Using data from São Paulo, Paraná, Mato Grosso do Sul, Goiás, Minas Gerais (expansion region of SVAA) and Mato Grosso States, another study estimates average sugarcane production costs to be between R$51.6- 61.45/ton, which translate to R$3508.80-7662.00/ha (PECEGE 2012).

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Tables

Table 1. Standard productivity by soil type. Yield estimates assume standard fertilization. The values are derived from existing studies in close proximity to our study area (Prado 2005).

Soil Type	Brazilian Soil Category	USDA Soil category	Yield (Ton/ha)	Soil fertility category
CXbe8	Cambisols (CAMBISSOLO HÁPLICO)	Inceptisols	100	High
GMd4	Gleisols (GLEISSOLO MELÂNICO)	Entisols	100	High
LVd1	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	86	Medium/low
LVd11	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	86	Medium/low
LVd2	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	86	Medium/low
LVd6	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	86	Medium/low
LVdf1	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	86	Medium/low
LVdf2	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	86	Medium/low
LVef1	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	98	High
LVef2	Latisols (LATOSSOLOS VERMELHO)	Red latosols (oxisols)	98	High
PVAd7	ARGISSOLO VERMELHO-AMARELO	Red-yellow ultisols	86	Medium/low
RQo1	NEOSSOLO QUARTZARÊNICO	Quartzipsamment	68	Medium/low

Table 2. Average sugarcane yield by municipality in Minas Gerais State (Source: the Brazilian Institute of Geography and Statistics).[4]

Municipality	Average Productivity (tons/ha)		
	2009	2010	2011
Santa Vitoria	80	80	76
Limeira do Oeste	85	85	85
União de Minas	90	90	90
Campina Verde		80	80
Gurinhatã	85	85.5	85.5
Ipiaçu	83	60	60
Ituiutaba	85	70	70
Gouvelandia	98	88	76
Quirinopolis	80	86	73
Paranaiguara	83	78	73
São Simão	105	78	73

[4] Accessed here: http://www.ibge.gov.br/cidadesat/index.php?lang=_EN

Table 3. Parameter values used in the sugarcane production model. We annualized costs that are incurred once per sugarcane cycle ("Every crop cycle") using a time frame of 6 years; we used 12 years for those incurred at the start of sugarcane production ("First crop cycle").

Parameter	Variable	Unit	Scale	Time incurred	Source
Price	Sugarcane price	R$/ton		annually	UDOP
Yield	Sugarcane yield	tons/ha	pixel	annually	Prado, 2005
Spatially variable costs					
Transportation Costs	Land transportation	R$/ton	pixel	annually	SVAA
	Barge costs	R$/ton	pixel	annually	SVAA
Fertilization Cost	Soil fertilization	R$/ton	pixel	Every crop cycle	SVAA
Leasing Costs	Leasing Cost	R$/ha	pixel	annually	SVAA
Replanting costs	Tree Removal	R$/ha	pixel	First crop cycle	SVAA
	Tree planting	R$/tree	pixel	First crop cycle	SVAA
Forest Code compliance costs	Restoration costs	R$/ha	pixel	First crop cycle	SVAA
	Fines for removing an existing LRs	R$/ha	pixel	First crop cycle	Decree nº 44.844, June 25th, 2008
	Fines for removing an existing PPA	R$/ha	pixel	First crop cycle	Decree nº 44.844, June 25th, 2008
Transaction Cost (spatial)	Legal Reserve Registration*	R$	farm	First crop cycle	SVAA
	PTRF/PRAD [5]*	R$	farm	First crop cycle	SVAA
	Forestry use permit*	R$	farm	First crop cycle	SVAA
	Technical appraisal of alternative location*	R$	farm	First crop cycle	SVAA
	Operation Permit	R$	farm	First crop cycle	SVAA
	Water Permit	R$	farm	First crop cycle	SVAA
Operational costs	Harvesting	R$/ton	pixel	annually	SVAA
	Handling	R$/ton	pixel	annually	SVAA
	Soil preparation (expansion areas)	R$/ha	pixel	Every crop cycle	SVAA
Spatially uniform costs					
Support	Operational support	R$/ha	pixel	annually	SVAA
Administrative		R$/ha	pixel	annually	SVAA
Soil preparation		R$/ha	pixel	Every crop cycle	SVAA
Sowing		R$/ha	pixel	Every crop cycle	SVAA
Management	Includes labor costs	R$/ha	pixel	annually	SVAA
Transaction Costs (non-spatial)	Includes prospecting cost, forest inventory*, topographic assessment, farm georeferencing costs*	R$/ha	pixel	First crop cycle	SVAA

[5] Plan for Recovery of Degraded Areas and Technical Project Reconstitution Flora

* Costs related to the Forest Code

Table 4. Mean values (and standard deviations) for parameters employed in the sugarcane optimization models (a standard deviation of 0 indicates non-spatially variable costs). All costs are given in R$ per pixel (0.81 ha) and determined over the entire study region. The Forest Code compliance costs pertain to pixels currently under natural vegetation or those that are selected for restoration. For confidentiality reasons, we cannot disclose the summary statistics for individual costs.

Parameter	Description	Mean Value
Production costs	Sum of transportation, fertilization*, leasing*, clearing, tree removal, transaction, harvesting*, handling*, administrative, support and management costs, and soil preparation*	**3917.69 (249.39)**
Transportation	Includes costs of transporting sugarcane from a pixel to the processing mill by roads or barge	Spatially-variable
Fertilization	Cost of applying the optimal amount of fertilizer per pixel of given soil type. Varies by soil type.	Spatially-variable
Leasing	Costs of renting a pixel per year. Determined by the proximity to the sugarcane processing mill and the yield per pixel. By assumption, the sugarcane producer must lease whole farms	Spatially-variable
Clearing	Cost of removing natural vegetation	Spatially-variable
Tree removal	Cost of clearing paddock trees from pastures that are selected for conversion to sugarcane	Spatially-variable
Transaction	Costs associated with leasing contracts and permit issuance	Spatially variable
Harvesting	Varies proportionally with the yield per pixel	Spatially-variable
Handling	Varies proportionally with the yield per pixel	Spatially-variable
Administrative	Non-spatial, includes administrative costs associated with sugarcane production	Non-spatially variable
Management	Non-spatial, includes costs related to the management of sugarcane fields (labor and transportation costs of field staff)	Non-spatially variable
Support	Field operational support costs (not included in other listed parameters)	Non-spatially variable
Soil preparation	Associated with preparing the soil for sugarcane. Existing sugarcane has lower costs. Includes uniform sowing costs	Spatially-variable

FC compliance costs		**142.58 (252.12)**
Deforestation fines	Fines imposed by the Env. Agency of natural vegetation is cleared. These range from R$800 to 2400 for Legal Reserves and R$900-2700 for PPAs. Because the actual values are left at the discretion of the Env. Agency, we use the annualized midpoint of the range	205.27 (0)
FC Transaction	Include costs of permits, technical plans and Legal Reserve registration	7.12 (4.30)
Pasture restoration	Costs of replanting trees removed from pastures. The State legislation requires planting 10 trees for each one cut. Costs vary spatially based on # paddock trees per pixel (quantified using aerial imagery of 2.5 m resolution for our study area)	5.89 (6.13)
Other restoration	Cost of restoring natural habitat; does not vary by habitat type	422.61 (0)
Other parameters		
Yield	Yield based on the soil type and slope	67.54 (15.56) tons/ pixel
Farm size	Based on spatially explicit farm boundaries for all properties w/in our study area	233.80 (296.84) ha

*Indicates the top 5 highest cost per pixel